DEPARTMENT OF MATHEMATICS
UNIVERSITY OF PESHAWAR

BS 4-year Programme in Mathematics 2015 and onward

Details of scheme of studies for the BS (Mathematics)

Compulsory Requirements 9 courses (Cr. hrs 25)	General Courses 7 courses (Cr. hrs 21)	Discipline Specific Foundation Courses 10 courses (Cr. Hrs 30)	Major courses 14 courses (Cr. hrs 42)	Elective Courses and Seminars 4 courses + 4 Seminars (Cr. hrs 12+4)
English-I (3)	Computation in MATLAB (3)	Calculus-I (3)	Number Theory (3)	E1 (3)
English-II (3)	Introduction to Statistics (3)	Calculus-II (3)	Real Analysis-I (3)	E2 (3)
English-III (3)	Computer Algebra System (2+1)	Calculus-III (3)	Real Analysis-II (3)	E3 (3)
Islamic Studies (2)	G1 (3)	Algebra-I (3)	Topology (3)	E4 (3)
Pakistan Studies (2)	G2 (3)	Algebra-II (3)	Classical Mechanics (3)	Seminars of 1 credit hour in each of the last four semesters
Discrete Mathematics (3)	G3 (3)	Linear Algebra (3)	Functional Analysis (3)	
Elements of Set Theory and Mathematical Logic (3)	G4 (3)	Complex Analysis (3)	Probability Theory (3)	
Introduction to Computers (2+1)		Ordinary Differential Equation (3)	Mathematical Methods (3)	
Affine and Euclidean Geometry (3)		Integral Equations (3)	Differential Geometry & Tensor Analysis (3)	
		Vector Analysis (3)	Partial Differential Equations-I (3)	
			Project (3)	
			Project (3)	
			Numerical Analysis-I (3)	
			Numerical Analysis-II (3)	

Semester and year wise breakdown of courses

First Year

First Semester			**Second Semester**		
Course code	**Course Title**	**Credit Hours**	**Course Title**	**Course Title**	**Credit Hours**
MATH-311	Calculus- I	3	MATH-321	Calculus II	3
MATH-312	Elements of set theory and Mathematical logic	3	MATH-322	Discrete Mathematics	3
---------------	English –I	3	---------------	English –II	3
---------------	Islamic Studies/ Ethics	2	--------------	Pakistan Studies	2
--------------	G-1	3	---------------	G-2	3
--------------	Introduction to computer	2+1	---------------	Introduction to Statistics	3
Total		**17**	**Total**		**17**

Second Year

Third Semester			**Fourth Semester**		
Course code	**Course Title**	**Credit Hours**	**Course code**	**Course Title**	**Credit Hours**
MATH-431	Calculus-III	3	MATH- 441	Vector Analysis	3
MATH-432	Computation in MATLAB	2+1	MATH-442	Ordinary differential equation	3
MATH-433	Linear Algebra	2 +1	MATH-443	Affine & Euclidean Geometry	3
---------------	English-III	3	MATH-444	Computer Algebra System	2+1
---------------	G-3	3	MATH-445	Number Theory	3
			--------------	G-4	3
Total		**15**	**Total**		**18**

Third Year

Fifth Semester			Sixth Semester		
Course code	**Course Title**	**Credit Hours**	**Course code**	**Course Title**	**Credit Hours**
MATH-551	Algebra I	3	MATH-561	Algebra II	3
MATH-552	Real Analysis I	3	MATH-562	Real Analysis II	3
MATH-553	Integral Equations	3	MATH-563	Partial Differential Equations	3
MATH-554	Topology	3	MATH-564	Complex Analysis	3
MATH-555	Mathematical Methods	3	MATH-565	Classical Mechanics	3
MATH-556	Guest/Student's Seminar	1	MATH-566	Guest/Student's Seminar	1
Total		**16**	**Total**		**16**

Fourth Year

Seventh Semester			Eighth Semester		
Course code	**Course Title**	**Credit Hours**	**Course code**	**Course Title**	**Credit Hours**
MATH-671	Probability Theory	3	MATH-681	Numerical Analysis-II	3
MATH-672	Differential Geometry and tensor analysis	3	MATH-682	Functional Analysis	3
MATH-673	Numerical Analysis-I	3	PROJ--683	Project	3
PROJ-674	Project	3	MATH-684	Guest/Student's Seminar	1
MATH-675	Guest/Student's Seminar	1	-------------	Elective III	3
-------------	Elective I	3	-------------	Elective IV	3
---------------	Elective II	3			
Total		**19**	**Total**		**16**

Note: In a semester system of education, courses are normally defined in terms of credit hours. Some courses have further sub-division into theory and lab work. One credit hour of theory work means one lecture hour in the classroom per week per semester (18 weeks). One credit hour of lab work however, is equivalent to two contact hours in the lab per week per semester.

1. Total credit hours for 1st year = 34
2. Total credit hours for 2nd year = 33
3. Total credit hours for 3rd year = 32
4. Total credit hours for 4th year = 35

Total credit hours for the BS Programme= 134

General Courses for BS Mathematics

The courses G-1, G-2, G-3 and G-4 may be chosen from following titles. This list may be extended with consent of Board of Studies keeping in view the availability of expertise in the University.

- Physics-I
- Physics-II
- Biology
- Economics
- Chemistry
- Accounting
- Psychology
- Sociology
- Philosophy
- Environmental Sciences

Elective Courses for BS Mathematics

Electives E-1, E-2, E-3 and E-4 will be selected from the following list of optional courses.

To be selected in semester 7.

- MATH-676 Fluid Mechanics
- MATH-677 Algebraic Topology
- MATH-678 Galois Theory
- MATH-679 Electromagnetism
- MATH-6710 Modeling and Simulations
- MATH-6711 Measure Theory
- MATH-6712 Rings and Modules
- MATH-6713 Projective Geometry
- MATH-6714 Riemannian Geometry
- MATH-6715 General Relativity
- MATH-6716 Mathematical Modeling
- MATH-6717 Axiomatic Set Theory

To be selected in Semester 8.

- MATH-685 Dynamical Systems
- MATH-686 Computational fluid dynamics
- MATH-687 History of Mathematics
- MATH-688 Pointless Topology
- MATH-689 Quantum Mechanics
- MATH-6810 Lie Groups and Lie Algebra
- MATH-6811 Introduction to Econometrics
- MATH-6812 Module Theory
- MATH-6813 Graph Theory
- MATH-6814 Special Relativity
- MATH-6815 Optimization Theory
- MATH-6816 Category Theory
- MATH-6817 Convex Analysis

MATH-311	Calculus-I	Credit Hours (3)

Prerequisites: Knowledge of Intermediate Calculus

Specific Objectives of Course: Calculus serves as the foundation of advanced subjects in all areas of mathematics. This is the first course of calculus. The objective of the course is to introduce students to the fundamental concepts of limit, Continuity, differential and integral calculus of functions of one variable.

Course Outline:

Equations and Inequalities: Solving linear and quadratic equations linear inequalities, division of polynomials, synthetic division, Roots of a polynomial, rational roots, Viete relations, Descartes rule of signs. Solutions of equations with absolute value sign, Solution of linear and non-linear inequalities with absolute value sign.

Functions and Graphs: Domain and range of a function examples polynomial, rational, piecewise defined functions, absolute value functions, and evaluation of such functions. Operations with functions: sum, product, quotient and composition Graphs of functions: linear, quadratic, piecewise defined functions,

Lines and systems of equations**:** Equation of a straight line, slope and intercept of a line, parallel and perpendicular lines, Systems of linear equations, solution of system of linear equations. Nonlinear systems: at least one quadratic equation.

Limits, and continuity: Functions, limit of a function, Graphical approach, Properties of limits, Theorems of limits, Limits of polynomials, rational and transcendental functions, Limits at infinity, infinite limits, one-sided limits, Continuity.

Derivatives: Definition, techniques of differentiation, Derivatives of polynomials and rational, exponential, logarithmic and trigonometric functions, The chain rule, Implicit differentiation, Rates of change in natural and social sciences, Related rates, Linear approximations and differentials, Higher derivatives, Leibnitz's theorem.

Applications of derivatives: Increasing and decreasing functions, Relative extrema and optimization, First derivative test for relative extrema, Convexity and point of inflection, The second derivative test for extrema. Curve sketching. n value theorems. Indeterminate forms and L. Hopitals rule, Inverse functions and their derivatives.

Integration: Anti derivatives and integrals. Riemann sums and the definite integral, Properties of Integral, The fundamental theorem of calculus, the substitution rule.

Recommended Books:

1. G. Thomas, "*Calculus*", 11th Edition. Addison Wesley Publishing Company, 2005
2. H. Anton, I. Sevens, S. Davis, "*Calculus*", 8th Edition, John Wiley & Sons, Inc. 2005
3. Hughes-Hallett, Gleason, McCallum, et al, "*Calculus Single and Multivariable*", 3rd Edition, John Wiley & Sons, Inc, 2002.
4. Frank A. Jr, Elliott Mendelson, "*Calculus*", Schaum's outlines series, 4th Edition, 1999
5. C.H. Edward and E.D Penney, "*Calculus and Analytics Geometry*", Prentice Hall, Inc. 1988
6. E. W. Swokowski, "*Calculus with Analytic Geometry*", PWS Publishers, Boston, Massachusetts, 1983.
7. M. Liebeck, "*A Concise introduction to pure Mathematics*", CRC Press, 2011.
8. A. Kaseberg, "*Intermediate Algebra*", Thomson Brooks/cole, 2004

MATH-312	Elements of set theory and Mathematical logic	Credit Hours (3)

Prerequisites: Knowledge of Intermediate Mathematics

Specific Objectives of course: Everything mathematicians do can be reduced to statements about sets, equality and membership which are basics of set theory. This course introduces these basic concepts. The course aims at familiarizing the students with cardinals, relations and fundamentals of prepositional and predicate logics.

Course Outline:

Set theory: Sets, subsets, operations with sets: union, intersection, difference, symmetric difference, Cartesian product and disjoint union.

Functions: graph of a function, Composition, injections, surjections, bijections, inverse function.

Computing cardinals: Cardinality of Cartesian product, union, Cardinality of all functions from a set to another set. Cardinality of all injective, surjective and bijective functions from a set to another set, Infinite sets, finite sets, Countable sets, properties, examples (Z, Q). R is not countable. R, RxR, RxRxR have the same cardinal, Operations with cardinal numbers, Cantor-Bernstein theorem.

Relations: Equivalence relations, partitions, quotient set; examples, parallelism, similarity of triangles. Order relations, min, max, inf, sup; linear order. Examples: N, Z, R, *P(A)*, Well-ordered sets and induction, Inductively ordered sets and Zorn's lemma.

Mathematical logic: Propositional Calculus, Truth tables, Predicate Calculus.

Recommended Books:

1. M. Liebeck, "*A Concise Introduction to Pure Mathematics*", CRC Press, 2011.
2. N. L. Biggs, " *Discrete Mathematics*", Oxford University Press, 2002. 3
3. R. Gamier, J. Taylor, "*Discrete Mathematics*", Chapters 1,3,4,5,CRC Press, 2010
4. A.A. Fraenkal, "*Abstract Set Theory*", North-Holland Publishing Company, 1966.
5. P. Suppes, "*Axiomatic Set Theory*", Dover Publication, 1972.
6. P.R. Halmos, "*Naive'Set Theory*", New York, Van Nostrand, 1950.
7. B. Rotman, G.T. Kneebone, "*The Theory of sets and Transfinite Numbers*", *o*ld bourne London. 1968.
8. D. Smith, M. Eggen, R.St. Andre, "*A Transition to Advanced Mathematics*", Books/Cole, 2001.

MATH-321	Calculus-II	Credit Hours (3)

Prerequisites: Calculus I

Specific Objectives of course: This is second course of Calculus. As continuation of Calculus I, it focuses on techniques of integration and applications of integrals. The course also aims at introducing the students to infinite series, parametric curves and polar coordinates

Course Outline:

Techniques of integration**:** Integrals of elementary, hyperbolic, trigonometric, logarithmic and exponential functions, Integration by parts, substitution and partial fractions, Approximate integration, Improper integrals. Gamma functions.

Applications of integrals: Area between curves, average value, Volumes, Arc length, Area of a surface of revolution, Applications to Economics, Physics, Engineering and Biology.

Infinite series: Sequences and series, Convergence and absolute convergence. Tests for convergence, divergence test, integral test, p-series test, comparison test, limit comparison test,

alternating series test, ratio test, root test. Power series, Convergence of power series., Representation of functions as power series, Differentiation and integration of power series, Taylor and Maclaurin series Approximations by Taylor polynomials.
Conic section, parameterized curves and polar coordinates, Curves defined by parametric equations, Calculus with parametric curves: tangents, areas, arc length. Polar coordinates. Polar curves, tangents to polar curves, Areas and arc length in polar coordinates.

Recommended Books:

1. G. Thomas, "*Calculus*", 11th Edition. Addison Wesley Publishing Company, 2005
2. H. Anton, I. Sevens, S. Davis, "*Calculus*", 8th Edition, John Wiley& Sons, Inc. 2005
3. Hughes-Hallett, Gleason, McCallum, et al, *Calculus Single and Multivariable*, 3rd Edition. John Wiley & Sons, Inc. 2002.
4. Frank A. Jr, Elliott Mendelson, "*Calculus*", Schaum's outlines series, 4th Edition, 1999
5. C.H. Edward and E.D Penney, "*Calculus and Analytics Geometry*", Prentice Hall, Inc. 1988
6. E. W. Swokowski, "*Calculus with Analytic Geometry*", PWS Publishers, Boston, Massachusetts, 1983.
7. M. Liebeck, "*A Concise introduction to pure Mathematics*", CRC Press, 2011
8. A. Kaseberg, "*Intermediate Algebra*", Thomson Brooks/COLE, 2004
9. J. Stewart, "Calculus early transcendental", 7th Edition, Brooks/COLE, 2008.

MATH-322	Discrete Mathematics	Credit Hours (3)

Specific Objectives of course: Discrete Mathematics is study of distinct, un-related topics of mathematics; it embraces topics from early stages of mathematical development and recent additions to the discipline as well. The present course restricts only to counting methods, relations and graphs. The objective of the course is to inculcate in the students the skills that are necessary for decision making in non-continuous situations.

Course Outline:

Counting methods: Basic methods, product, inclusion-exclusion; formulae, Permutations and combinations Recurrence relations and their solutions, Generating functions, Double counting, Applications, pigeonhole principle, applications.
Relations: Binary relations, n-array Relations, Closures of relations, Composition of relations, inverse relation.
Graphs: Graph terminology, Representation of graphs, Graphs isomorphism. Algebraic methods: the incidence matrix, Connectivity, Eulerian and Hamiltonian paths, Shortest path problem, Trees and spanning trees. Complete graphs and bivalent graphs.

Recommended Books:

1. B. Bollobas, "*Graph Theory*", Springer Verlag, New York, 1979.
2. K.R. Parthasarathy, "*Basic Graph Theory*", McGraw-Hill, 1994
3. K.H. Rosen, "*Discrete Mathematics and its Application*",McGraw-Hill, 6th edition, 2007.
4. B. Kolman, R.C. Busby, S.C. Ross, "*DiscreteMathematical Structures*",
5. Prentice-Hall of India, New Delhi, 5thedition, 2008.
6. Tucker, "*Applied Combinatorics*", John Wiley and Sons, Inc New York, 2002
7. R. Diestel, "*Graph Theory*", 4th edition. Springer- Verlag, NewYork, 2010.
8. N.L. Brigs, "*Discrete Mathematics*", Oxford University Press, 2003 .
9. K.A. Ross, C.R.B. Wright, "*Discrete Mathematics*". Prentice Hall, New Jersey, 2003.

MATH-431	Calculus-III	Credit Hours (3)

Prerequisites: Calculus-II

Specific Objectives of course: This is third course of Calculus and builds up on the concepts learned in first two courses. The students would be introduced to the vector calculus, the calculus of multivariable functions and double and triple integrals along with their applications.

Course Outline:

Vectors and analytic geometry in space: Coordinate system, Rectangular, cylindrical and spherical coordinates, the dot product, the cross product, Equations of lines and planes, Quadric surfaces.

Vector-valued functions: Vector-valued functions and space curves. Derivatives and integrals of vector valued functions, Arc length Curvature, normal and binormal vectors.

Multivariable functions and partial derivatives: Functions of several variables, Limits and Continuity. Partial derivatives, Composition and chain rule, Directional derivatives and the gradient vector, Implicit function theorem for several variables, Maximum and minimum values, Optimization problems, Lagrange Multipliers.

Multiple integrals: Double integrals over rectangular domains and iterated integrals, Non-rectangular domains, Double integrals in polar coordinates. Triple integrals in rectangular, cylindrical and spherical coordinates, Applications of double and triple integrals. Change of variables in multiple integrals.

Vector calculus: Vector fields, Line integrals, Green's theorem, Curl and divergence, Surface integrals over scalar and vector fields, Divergence theorem, Stokes' theorem.

Recommended Books:

1. *G. Thomas, "Calculus", 11th Edition. Addison. Wesley Publishing Company, 2005*
2. *H. Anton, I. Bevens, S. Davis," Calculus", 8th Edition, John Wiley &Sons, Inc. 2005*
3. *H ughes-Hallett, Gleason, McCallum, et al, "Calculus Single and Multivariable", 3rd Edition. John Wiley & Sons, Inc. 2002.*
4. *Frank A. Jr, Elliott Mendelson, "Calculus, Schaum's outlines series", 4lh Edition, 1999*
5. *C.H. Edward and E.D Penney, "Calculus and Analytics geometry", Prentice Hall, Inc. 1988*
6. *E. W. Swokowski, "Calculus with Analytic Geometry", PWS Publishers, Boston, Massachusetts, 1983.*
7. *M. Liebeck, "A Concise introduction to pure Mathematics", CRC Press, 2011.*
8. *A. Kaseberg, "Intermediate Algebra", Thomson Brooks/COLE, 2004.*
9. *J. Stewart, "Calculus early transcendental", 7th Edition, Brooks/COLE, 2008.*

MATH-432	Computation in MATLAB	Credit Hours 3 (2 +1)

Prerequisite: Introduction to computers

Specific Objectives of the course: After this course students will be able to write small programs for mathematical problems. Students will be able to perform computations in MATLAB.

Course outline: Introduction to MATLAB windows, built in functions, arrays, matrices, script files, plots, functions and function files, loops, selection statements, polynomials, curve fitting and interpolation

Recommended Books:

1. *B. Hunt, R. Lipsman, J. Rosenberg, "A guide to Matlab", Cambridge, 2001.*
2. *Etter, D.M., Kuncicky, D. and Hull, D., "Introduction to MATLAB 6", Prentice Hall, Englewood Cliffs, NJ, USA, 2001.*

MATH-433	**Linear Algebra**	**Credit Hours (3)**

Prerequisites: Calculus I

Specific objectives of course: linear algebra is the study of vector spaces and linear transformations. The main objective of this course is to help students learn in rigorous manner, the tools and methods essential for studying the solution spaces of problems in mathematics, engineering, the natural sciences, and social sciences and development mathematical skills needed to apply these to the problems arising within their field of study; and to various real wold problems.

Course Outline:

System of Linear Equations: Representation in matrix form. Matrices. Operations on matrices. Echelon and reduced echelon form. Inverse of a matrix (by elementary row operations) Solution of linear system. Gauss-Jordan method. Gaussian elimination.

Determinants: Permutations of order two and three and definitions of determinants of the same order. Computing of determinants. Definition of higher order determinants. Properties. Expansion of determinants.

Vector Spaces: Definition and examples., subspaces. Linear combination and spanning set. Linearly Independent sets. Finitely generated vector spaces. Bases and dimension of a vector space. Operations on subspaces, Intersections, sums and direct sums of subspaces. Quotient Spaces

Linear mappings: Definition and examples. Kernel and image of a linear mapping. Rank and nullity Reflections, projections^ and homotheties. Change of basis. Eigen-values and eigenvectors Theorem of Hamilton-Cayley.

Inner product Spaces: Definition and examples. Properties. Projection. Cauchy inequality. Orthogonal and orthonormai basis. Gram Schmidt Process. Diagonalization.

Recommended Books:

1. Ch. W. Curtis, "*Linear Algebra*", Springer 2004.
2. T. Apostol, "*Multi Variable Calculus and Linear Algebra*", 2nd ed., John Wiley and sons, 1997
3. H. Anton, C. Rorres , "*Elementary Linear Algebra: Applications Version*", 10th Edition, John Wiley and sons, 2010.
4. S. Friedberg, A. Insel, "Linear Algebra", 4th Edition, Pearson Education Canada, 2003.
5. S. I. Grossman, "*Elementary Linear Algebra*", 5lh Edition, Cengage Learning, 2004.

MATH-441	**Vector Analysis**	**Credit Hours (3)**

Prerequisites: Calculus-II

Specific Objectives of the Course:

This course shall assume background in calculus. It covers basic principles of vector analysis, which are used in mechanics

Course Outline:

3-D vectors, summation convention, kronecker delta, Levi-Civita symbol, vectors as quantities transforming under rotations with ϵ_{ijk} notation, scalar and vector-triple products, scalar and vector-point functions, differentiation and integration of vectors, line integrals, path independence, surface integrals, volume integrals, gradient, divergence and curl with physical significance and applications, vector identities, Green's theorem in a plane, divergence theorem, Stokes' theorem, coordinate systems and their bases, the spherical-polar and the cylindrical-coordinate.

Recommended Books:

1. *Bourne DE, Kendall PC, "Vector Analysis and Cartesian Tensors", 2nd edition, Thomas Nelson*
2. *Shah NA, "Vector and Tensor Analysis", 2005 A-One Publishers, Lahore*
3. *Smith GD, "Vector Analysis", Oxford University Press, Oxford*
4. *Spiegel MR, "Vector Analysis", 1974, McGraw Hill, New York*
5. *M. Afzal Qazi, "A First Course on Vectors", West Pakistan Publishing Co. Lahore.*

MATH-442	Ordinary Differential Equations	Credit Hours (3)

Prerequisites: Calculus I

Specific Objectives of course: To introduce students to the formulation, classification of differential equations and existence and uniqueness of solutions. To provide skill in solving initial value and boundary value problems. To develop understanding and skill in solving first and second order linear homogeneous and non-homogeneous differential equations and solving differential equations using power series methods.

Course Outline:

Preliminaries: Introduction and formulation, classification of differential equations, existence and uniqueness of solutions, introduction of initial value and boundary value problems
First order ordinary differential equations: Basic concepts, formation and solution of differential equations. Separable variables, Exact Equations, Homogeneous Equations, Linear equations, integrating factors. Some nonlinear first order equations with known solution, differential equations of Bernoulli and Ricaati type, Clairaut equation, modeling with first-order ODEs, Basic theory of systems of first order linear equations, Homogeneous linear system with constant coefficients, Non homogeneous linear system
Second and higher order linear differential equations: Initial value and boundary value problems, Homogeneous and non-homogeneous equations, Superposition principle, .homogeneous equations with constant coefficients, Linear independence and Wronskian, Non-homogeneous equations, undetermined coefficients method, variation of parameters, Cauchy-Euler equation,
Modeling. Sturm-Liouville problems: Introduction to eigen value problem, adjoint and self adjoint operators, self adjoint differential equations, eigen values and eigen functions, Sturm-Liouville (S-L) boundary value problems, regular and singular S-L problems, properties of regular S-L problems
Series Solutions: Power series, ordinary and singular points, existence of power series solutions, power series solutions, types of singular points, Frobenius theorem, existence of Frobenius series solutions, solutions about singular points, The Bessel, modified Bessel Legendre and Hermite equations and their solutions.

Recommended Books:

1. Dennis G. Zill and Michael R., "Differential equations with boundary-value problems", 5th Edition Brooks/Cole, 1997.
2. William E. Boyce and Richard C. Diprima', "Elementary differential equations and boundary value problems", Seventh Edition John Wiley & Sons, Inc

3. V. I. Arnold, "*Ordinary Differential Equations*", Springer, 1991.
4. T.Apostol, "*Multi Variable Calculus and Linear Algebra*",2nd ed., J. Wiley and sons. 1997.

MATH-443	Affine and Euclidean Geometry	Credit Hours (3)

Prerequisites: Calculus-I

Specific Objectives of course: To familiarize mathematics students with the axiomatic approach to geometry from a logical, historical, and pedagogical point of view and introduce them with the basic concepts of Affine Geometry, Affine spaces and Platonic Ployhedra.

Course Outline:
Vector spaces and affine geometry: Collinearity of three points, ratio AB/BC. Linear combinations and linear dependent set versus affine combinations and affine dependent sets. Classical theorems in affine geometry: Thales, Menelaus, Ceva, Desargues. Affine subspaces, affine maps. Dimension of a linear subspace and of an affine subspace.
Euclidean geometry: Scalar product, Cauchy-Schwartz inequality: norm of a vector, distance between two points, angles between two non-zero vectors. Pythagoras theorem, parallelogram law, cosine and sine rules. Elementary geometric loci.
Orthogonal transformations: Isometries of plane (four types), Isometries of space (six types). Orthogonal bases.
Platonic polyhedra: Euler theorem on finite planar graphs. Classification of regular polyhedra in space. Isometries of regular polygons and regular polyhedra.

Recommended Books:
1. E. Rees, "*Notes on Geometry*", Springer, 2004.
2. M. A. Armstrong, "*Groups and Symmetry*", Springer, 1998.
3. H. Eves, "*Fundamentals of Modern Elementary Geometry*", Jones and Bartlett Publishers International, 1992
4. S. Stahl, "*The Poincare Half-Plane A Gateway to Modern Geometry*", Jones and Bartlett Publishers International, 1993.

MATH-444	Computer Algebra System	Credit Hours 3 (2 +1)

Prerequisite: Introduction to computers, Computation in MATLAB.

Specific objectives of the course: Students at the end of the course will be able to perform analytical work of algebra and other related mathematical problems with the help of computer softwares like MAPLE or MATHEMATICA.

Course outline: Numerical Calculations, Exact and approximate results, Complex Numbers, Algebraic calculations, Limits, Differentiation, Integration, Sums and Products, Solving equations, Solving ordinary and partial differential equations, Power series, Integral Transforms, Numerical Solutions (sums, products, differentiation, integration, solving equations, solving differential equations), Defining functions, Vectors and Matrices, Two and Three dimensional Graphics, Parametric and Density Plots, Polar plots.

Recommended books:

1. Martha L. Abell, James P. Braselton, “Mathematica by Examples”, Third Edition, Elsevier Academic Press, 2004.
2. Stephen Wolfram, “ Mathematica”, 5th Edition, Wolfram Media, 2003.
3. John S. Devitt, “Calculus with Maple V”, Brooks/Cole, 1993

MATH-445	Number Theory	Credit Hours (3)

Prerequisites: Linear Algebra

Specific Objectives of course: The focus of the course is on study of the fundamental properties of integers and-develops ability to prove basic theorems. The specific objectives Include study of division algorithm, prime numbers and their distributions, Diophantine equations, and the theory of congruences

Course Outline:
Preliminaries: Well-ordering principle. Principle of finite induction.
Divisibility theory: The division algorithms. Basis representation theorem. Prime and composite numbers. Canonical decomposition. The greatest common divisor. The Euclidean algorithm. The fundamental theorem of arithmetic. Least common multiple.
Linear Diophantine equations: Congruences. Linear congruences. System of linear congruences. The Chinese remainder theorem. Divisibility tests. Solving polynomial congruences. Fermat's and Euler's theorems. Wilson's theorem.
Arithmetic functions: Euler's phi-function. The functions of J and sigma. The Mobius function. The sieve of Eratosthenes. Perfect numbers. Fermat and Mersenne primes.
Primitive Roots and Indices: The order of an integer mod n. Primitive roots for primes. Composite numbers having primitive roots.
Quadratic residues: Legendre symbols and its properties. The quadratic reciprocity law. Quadratic congruences with composite moduli. Pythagorean triples. Representing numbers as sum of two squares.

Recommended Books:

1. *D.M. Burton, “Elementary Number Theory”, McGraw-Hill, 2007.*
2. *W.J. Leveque, “Topics in Number Theory”, vols. I and II, Addison-Wesley, 1956*
3. *S.B. Malik , “Basic Number Theory”, Vikas Publishing house, 1995*
4. *K.H. Rosen, “Elementary Number Theory and its Applications”, 5th edition, Addison-Wesley, 2005*
5. Niven, H.S. Zuckerman, H.L. Montgomery, “An Introduction to the theory of Numbers”, John Wiley and Sons, 1991.
6. Adler, J.E. Coury, “The Theory of Numbers”, Jones and Bartlett Publishers, 1995.

MATH-551	Algebra-I (Group Theory)	Credit Hours (3)

Prerequisites: Elements of Set Theory and Mathematical Logic

Specific Objectives of course: This course introduces basic concepts of groups and their homeomorphisms. The main objective of this course is to prepare students for courses which require a good back ground in group theory like Rings and Modules, Linear Algebra, Group Representation, Galois Theory etc.

Course Outline:

Groups: Definition of a group, subgroup, subgroup generated by a set. The cyclic groups, cosets and Lagrange's theorem. Normalizer centralizer. The center of a group. Equivalence relation in a group, conjugacy classes. Normal subgroups, quotient group. Group homomorphisms: Homomorphisms and isomorphism and Automorphism. Kernel and image of homomorphism. Isomorphism theorems. Permutation groups. The cyclic decomposition of a permutation group. Cayley's theorem. Direct product of two groups and examples.

Recommended Books:

1 J. Rose. *"A Course on Group Theor"*, Cambridge University Press, 1978.
2 I. N Herstein. "*Topics in Algebra"*, Xerox Publishing Company, 1964.
3 P. M. Cohn. "*Algebra"*, John Wiley and Sons, London, 1974.
4 P. B. Bhattacharya, S. K. Jain and S. R. Nagpaul, "*Basic Abstract Algebra"*, Cambridge University Press, 1986.
5 J B. Fraleigh, "*A First Course in Abstract Algebra"*, Addison- Wesiey Publishing Company, 2002.
6 Vivek Sahai and Vikas Bist, "*Algebra"*, Narosa Publishing House, 1999.
7 D. S. Dummit and R. M. Foote, "*Abstract Algebra"*, 3rd Edition, Addison-Wesley Publishing Company, 2004.

MATH-552	Real Analysis-I	Credit Hours (3)

Prerequisites: Calculus-III

Specific Objectives of Course: This is the first course in analysis. It develops the fundamental ideas of analysis and is aimed at developing the students' ability in reading and writing mathematical proofs. Another objective is to provide sound understanding of the axiomatic foundations of the real number system, in particular the notions of completeness and compactness

Course Outline:

Number Systems: Ordered fields. Rational, real and complex numbers. Archimedean property, supremum, infimum and completeness.

Topology of real numbers: Convergence, completeness, completion of real numbers. Open sets, closed sets, compact sets. Heine Borel Theorem. Connected sets. Sequences and Series of Real Numbers: Limits of sequences, algebra of limits. Bolzano Weierstrass Theorem. Cauchy sequences,

liminf, limsup. Limits of series, convergences tests, absolute and conditional convergence Power series.

Continuity: Functions, continuity and compactness, existence of; minimizers and maximizers, uniform continuity. Continuity andij connectedness, Intermediate mean Value Theorem. Monotone functions and discontinuities.

Differentiation: Mean Value Theorem, L'Hopital's Rule, Taylor'sl Theorem.

Recommended Books:

1. S. Lang, "Analysis", Addison-Wesley Publ. Co Reading, Massachusetts, 1968
2. W. Rudin, "*Principles of Mathematical Analysis"*, 3rd ed., Mc.Graw- Hill, 1976.
3. B. S. Thomson, J. B. Bruckner and A. M. Bruckner, "*Elementary Real Analysis"*. 2nd Ed. 2008.
4. G. Boros, V. Moll, "*Irresistible Integrals: Symbolics, Analysis an Experiments in the Evaluation of Integrals"*, Cambridge University Press, 2004.
5. J. Borwein, D. Bailey, R. Girgenson, "*Experimentation in Mathematics: Computational Paths to discovery"*, Wellesley, MA, A.K. Peters, 2004.

5. G. Bartle , R. Sherbert , "*Introduction to Real Analysis"*, 3 edition, John Wiley, New York, 1999.

MATH-553	Integral Equations	Credit Hours (3)

Prerequisites: Ordinary Differential Equations

Specific Objectives of course: Many physical problems that are usually solved by differential equation methods can be solved more effectively by integral equation methods. This course will help students gain insight into the application of advanced mathematics and guide them through derivation of appropriate integral equations governing the behavior of several standard physical problems.

Course Outline:
Linear integral equations of the first kind, Linear integral equations of the second kind. Relationship between differential equation and Volterra integral equation Neumann series. Fredholm Integral equation of the second kind with separable Kernels. Eigenvalues and eigenvectors. Iterated functions. Quadrature methods. Least square methods. Homogeneous integral equations of the second kind. Fredholm integral equations of the first kind. Fredholrn integral equations of the second kind. Abel's integral equations. Hilbert Schmidt theory of integral equations with symmetric Kernels Regularization and filtering techniques.

Recommended Books

1. C. T. C Baker, "Integral Equations", Clarendon Press. 1977.
2. F. Smithies, "Integral Equations", Cambridge University Press, 1989
3. M. Wazwaz, "A first Course in Integral Equations", World Scientific Pub., 1989.
4. W. V. Lovitt, "Linear Integral Equations", Dover Publications, 2005

MATH-554	Topology	Credit Hours (3)

Prerequisites: Calculus I

Specific Objectives of course: The aim of this course is to introduce the students to metric spaces and topological spaces. After completion of this course, they would be familiar with separation axioms, compactness and completeness. They would be able to determine whether a function defined on a metric or topological space is continuous, or not and what homeomorphisms are.

Course Outline:
Topological spaces: Examples; open and closed subsets, metric spaces, neighborhoods. Examples. Limit points and accumulation points. Interior, closure, dense subsets. Constructing new topological spaces: Cartesian products, induced topology and quotient topology. Continuous maps, open and closed maps, homeomorphisms. Examples: R, RxR, S^A1, S^A2, torus, cylinder. Cauchy sequences, complete metric spaces. Separation axioms. Compact spaces. Properties. Power of Compactness. Image of a compact set through a continuous map. Compactness and completeness of metric spaces.
Connected spaces, connected components. Properties, image of a connected set through a continuous map. Path-connectedness.

Recommended Books:

1. J. Keliy, "*General Topology"*, Springer, 2005.
2. K. Janich, "*Topology"*, Springer, 1994.

3. J. Hocking, G. Young, "*Topology*", Dover Publications, 1961.
4. J. R. Munkres, "*Topology - A First Course*", Prentice-Hall, 2003.
5. G. Simmons, "*Topology and modern analysis*", McGraw-Hill, 1963.
6. S. Lipschutz, "*General Topology*", McGraw-Hill, 2004.
7. J. Dugundji, "*Topology*", Allyn and Bacon, 1966.

MATH-555	Mathematical Methods	Credit Hours (3)

Prerequisites: Calculus-III

Specific Objectives of course: The main objective of this course is to provide the students with a range of mathematical methods that are essential to the solution of advanced problems encountered in the fields of applied physics and engineering. In addition this course is intended to prepare the students with mathematical tools and techniques that are required in advanced courses offered in the applied physics and engineering programs.

Course Outline:
Fourier Methods: The Fourier transforms. Fourier analysis of the generalized functions. The Laplace transforms. Hankel transforms for the solution of PDEs and their application to boundary value problems.
Green's Functions and Transform Methods: Expansion for Green's functions. Transform methods. Closed form Green's functions.
Perturbation Techniques: Perturbation methods for algebraic equations. Perturbation methods for differential equations.
Variational Methods: Euler-Lagrange equations. Integrand involving one, two, three and n variables. Special cases of Euler-lagrange's equations. Necessary conditions for existence of an extremum of a functional. Constrained maxima and minima.

Recommended Books:

1. D. L. Powers, "*Boundary Value Problems and Partial Differential Equations*", 5lh edition, Academic Press, 2005.
2. W E. Boyce, "*Elementary Differential Equations*", 8lh edition, John Wiley and Sons, 2005.
3. M. L. Krasnov, G. I. Makarenko and A. I. Kiselev, "*Problems and Exercises in the Calculus of Variation*", Imported Publicat ions. Inc.. 1985.
4. j. W. Brown and R. V. Churchil, "Fourier Series and Boundary Value Problems", McGraw Hill, 2006.
5. A. D. Snider, "*Partial Differential Equations: Sources and Solutions*", Prentice Hall Inc., 1999

MATH-556	Seminar	Credit Hours (1)

Participation in seminar of one credit hour in each of the last four semesters is compulsory. The students may set in the weekly departmental seminars or each student will present a talk from their courses. However, no value is assigned in grading the seminar.

MATH-561	Algebra-II	Credit Hours (3)

Prerequisites: Algebra-I

Specific Objectives of course: This is a course in advanced abstract algebra, which builds on the concepts learnt in Algebra I. The objectives of the course are to introduce students to the basic ideas and methods of modern algebra and enable them to understand the idea of a ring and an integral domain, and be aware of examples of these structures in mathematics; appreciate and be able to prove the basic results of ring theory; appreciate the significance of unique factorization in rings and integral domains

Course Outline:
Rings: Definition, examples. Quadratic integer rings Examples of non-commutative rings. The Hamilton quaternions. Polynomial rings. Matrix rings. Units, zero-divisors, nilpotents, idempotents. Subrings, Ideals. Maximal and prime Ideals. Left, right and two-sided ideals;. Operations with ideals. The ideal generated by a set. Quotient rings. Ring homomorphism. The isomorphism theorems, applications. Finitely generated ideals. Rings of fractions.
Integral Domain: The Chinese remainder theorem. Divisibility in integral domains, greatest common divisor, least common multiple. Euclidean domains. The Euclidean algorithm. Principal ideal domains. Prime and irreducible elements in an integral domain. Gauss lemma, irreducibility criteria- for polynomials. Unique factorization domains. Finite fields. Polynomials in several variables. Symmetric polynomials. The fundamental theorem of symmetric polynomials.

Recommended Books:

1. J. Rose, "*A Course on Group Theory*", Cambridge University Press, 1978.
2. I. N. Herstein, "*Topics in Algebra*", Xerox Publishing Company, 1964.
3. P. M. Cohn, "*Algebra*", John Wiley and Sons, London, 1974.
4. P. B. Bhattacharya, S. K. Jain and S. R. Nagpaul, "*Basic Abstract Algebra*", Cambridge University Press, 1986.
5. J. B. Fraleigh, "*A First Course in Abstract Algebra*", Addison- Wesley Publishing Company, 2002.
6. Vivek Sahai and Vikas Bist, "*Algebra*", Narosa Publishing House, 1999
7. D. S. Dummit and R. M. Foote, "*Abstract Algebra*", 3rd Edition, Addison-Wesley Publishing Company, 2004.

MATH-562	Real Analysis-II	Credit Hours (3)

Prerequisites: Analysis-I

Specific Objectives of course: A continuation of Real Analysis !, this course will continue to cover the fundamentals of real analysis, concentrating on the Riemann-Stieltjes integrals, Functions of Bounded Variation, Improper Integrals, and convergence of series Emphasis would be on proofs of main results,

Course Outline:

The Riemann-Stieltjes Integrals: Definition and existence of integrals. Properties of integrals. Fundamental theorem of calculus and its applications. Change of variable theorem. Integration by parts.
Functions of Bounded Variation: Definition and examples. Properties of functions of bounded variation.
Improper Integrals: Types of improper integrals, tests for convergence of improper integrals. Beta and gamma functions. Absolute and conditional convergence of improper integrals.
Sequences and Series of Functions**:** Power series, definition of point-wise and uniform convergence. Uniform convergence and continuity. Uniform convergence and differentiation. Examples of uniform convergence.

Recommended Books:

1. S. Lang, "*Analysis I, II*", Addison-Wesley Publ. Co., Reading, Massachusetts, 1968,1969.
2. W. Rudin, "*Principles of Mathematical Analysis*", 3™ Ed., McGraw-Hill, 1976.
3. K. R. Davidson and A. P. Donsig, "*Real Analysis with Real Applications*", Prentice Hall Inc., Upper Saddle River, 2002.
4. G. B. Folland, "*Real Analysi"s*, 2nd Edition, John Wiley and Sons, New York, 1999.
5. E. Hewitt and K. Stromberg, "*Real and Abstract Analysis*", Springer-Verlag, Berlin Heidelberg New York, 1965.
6. H. L. Royden, " *Real Analysis*", 3rd Edition, Macmillan, New York, 1988.
7. G. Bartle , R. Sherbert, "*Introduction to Real Analysis*", 3 edition, John Wiley, New York, 1999.

MATH-563	Partial Differential Equations	Credit Hours (3)

Prerequisites: Ordinary Differential Equations

Specific Objectives of course: Partial Differential Equations (PDEs) are at the heart of applied mathematics and many other scientific disciplines. The course aims at developing understanding about fundamental concepts of PDEs theory, identification and classification of their different types, how they arise in applications, and analytical methods for solving them. Special emphasis would be on wave, heat and Laplace equations.

Course Outline:

First order PDEs: Introduction, formation of PDEs, solutions of PDEs of first order, The Cauchy's problem for quasilinear first order PDEs, First order nonlinear equations, Special types of first order equations Second order PDEs: Basic concepts and definitions, Mathematical problems, Linear operators, Superposition, Mathematical models: The classical equations, the' vibrating string, the vibrating membrane, conduction of heat solids, canonical forms and variable, PDEs of second order in two independent variables with constant and variable coefficients, Cauchy's problem for second order PDEs in two independent variables
Methods of separation of variables: Solutions of elliptic, parabolic hyperbolic PDEs in Cartesian and cylindrical coordinates a place transform: Introduction and properties of Laplace transform, transforms of elementary functions, periodic functions, error function and Dirac delta function, inverse Laplace transform, convolution theorem, solution of PDEs by Laplace transform, Diffusion and wave equations
Fourier transforms; Fourier integral representation, Fourier sine and cosine representation, Fourier transform pair, transform of elementary functions and Dirac delta function, finite Fourier transforms, solutions of heat, wave and Laplace equations by Fourier transforms

Recommended Books:

1. Myint UT, "*Partial Differential Equations for Scientists and Engineers*", 3 edition, North Holland, Amsterdam, 1987.
2. Dennis G. Zill, Michael R. Cullen, "*Differential equations with boundary value Problems*", Brooks Cole, 2008.
3. John Polking, Al Boggess, "*Differential Equations with Boundary Value Problems*", 2nd
4. Edition, Pearson. July 28, 2005
5. J. Wloka, "*Partial Differential Equations*", Cambridge University press, 1987.

MATH-564	Complex Analysis	Credit Hours (3)

Prerequisites: Analysis-I

Specific Objectives of course: This is an introductory course in complex analysis, giving the basics of the theory along with applications, with an emphasis on applications of complex analysis and especially conformal mappings. Students should have a background in real analysis (as in the course Real Analysis I), including the ability to write a simple proof in an analysis context.

Course Outline:

Introduction: The algebra of complex numbers, Geometric representation of complex numbers. Powers and roots of complex numbers.

Functions of Complex Variables: Definition, limit and continuity

Branches of functions, Differentiate and analytic functions The Cauchy-Riemann equations, Entire functions, Harmonic functions, Elementary functions: The exponential, Trigonometric, Hyperbolic, Logarithmic and Inverse elementary functions, Open mapping theorem Maximum modulus theorem.

Complex Integrals: Contours and contour integrals, Cauchy-Goursat theorem. Cauchy integral formula, Lioville's theorem, Morerea's theorem

Series: Power series, Radius of convergence and analyticity, Taylor's and Laurent's series, Integration and differentiation of power series.

Singularities, Poles and residues: Zero, singularities. Poles and Residues, Types of singular points, Calculus of residues, contour integration, Cauchy's residue theorem with applications. Mobius transforms, Conformal mappings and transformations.

Recommended Books:

1. R. V. Churchill, J. W. Brown, "*Complex Variables and Applications*" , 5 edition, McGraw Hill, New York, 1989.
2. J. H. Mathews and R. W. Howell, "*Complex Analysis for Mathematics and Engineering*", 2006.
3. S Lang, "*Complex Analysis*", Springer-Verlag, 1999.
4. R. Remmert, "*Theory of Complex Functions*", Springer-Verlag, 1991.
5. W. Rudin, "*Real and Complex Analysis*", McGraw-Hill, 1987.

MATH-565	Classical Mechanics	Credit Hours (3)

Prerequisites: Calculus-I

Specific Objectives of course: To provide solid understanding of classical mechanics and enable the students to use this understanding while studying courses on quantum mechanics, statistical mechanics, electromagnetism, fluid dynamics, space-flight dynamics, astrodynamics and continuum mechanics.

Course Outline:
Statics: Composition of forces, centers of mass and gravity, friction.
Kinematics: Rectilinear motion of particles. Uniform rectilinear motion, uniformly accelerated rectilinear motion. Curvilinear motion of particle, rectangular components of velocity and acceleration. Tangential and normal components. Radial and transverse components. Projectile motion.
Kinetics: Work, power, kinetic energy, conservative force fields, conservation of energy, impulse, torque. Conservation of linear and angular momentum. Non-conservative forces.
Simple Harmonic Motion: The simple harmonic oscillator, period, frequency. Resonance and energy. The damped harmonic oscillator, over damped, critically damped and under damped motion, forces and vibrations.
Central Forces and Planetary Motion**:** Central force fields, equations of motion, potential energy, orbits. Kepler's law of planetary motion, Apsides and apsidal angles for nearly circular orbits.
Planer Motion of Rigid Bodies: Introduction to rigid and. elastic bodies, degree of freedom, translations, rotations, instantaneous axis and center of rotation, motion of the center of mass. Euler's theorem and Chasles' theorem. Rotation of a rigid body about a fixed axis, moments and products of inertia. Parallel and perpendicular axis theorem.
Motion of Rigid Bodies in Three Dimensions: General motion of rigid bodies in space.

Recommended Books:

1. E. DiBenedetto, *Classical Mechanics. "Theory and Mathematical Modeling"*, ISBN: 978-0-8176-4526-7, Birkhauser Boston, 2011.
2. John R. Taylor, "*Classical Mechanics"*, ISBN: 978-1-891389-22-1, University of Colorado, 2005.
3. H. Goldstein, "*Classical Mechanics"*, Addison-Wesley Publishing Co., 1980.
4. C. F. Chorlton, "*Text Book of Dynamics"*, Ellis Norwood, 1983.
5. M. R. Spiegel, "*Theoretical Mechanics"*, 3rd Edition, Addison-Wesley Publishing Company, 2004.
6. G. R. Fowles and G. L. Cassiday, "*Analytical Mechanics", 7th* edition, Thomson Brooks/COLE, USA, 2005.
7. Q. K. Ghori, "Introduction to mechanics", revised Ed., Lahore, 1971.

MATH-671	Probability Theory	Credit Hours (3)

Prerequisites: Statistics

Specific Objectives of course: A prime objective of the course is to introduce the students to the fundamentals of probability theory and present techniques and basic results of the theory and illustrate these Concepts with applications. This course will also present the basic principles of random variables and random processes needed in applications.

Course Outline:
Finite probability spaces: Basic concept, probability and frequency, combination of events, examples, Independence, Random variables, Expected value. Standard deviation and Chebyshev's inequality. Independence of random variables. Multiplicativity of the Expected value. Additivity of the variance, Discrete probability distribution.
Probability as a continuous set function: Sigma-algebras, examples. Continuous random variables, Expectation and variance, Normal random variables and continuous probability distribution.

Applications: de Moivre-Laplace limit theorem, weak and strong law of large numbers.The central limit theorem, Markov chains and continuous Markov process.

Recommended Books:

1. M. Capinski, E. Kopp, “*Measure, Integral and Probability”*, Springer-Verlag, 1998.
2. R. M. Dudley, “*Real Analysis and Probability”*, Cambridge University Press, 2004.
3. S. I. Resnick, “*A Probability Path”*, Birkhauser, 1999.
4. S. Ross, “*A first Course in Probability Theory”*, 5th ed., Prentice Hall, 1998.
5. Robert B. Ash, “*Basic Probability Theory”*, Dover. B, 2008.

MATH-672	Differential Geometry and Tensor Analysis	Credit Hours (3)

Prerequisites: Calculus-I

Specific Objectives of course: After having completed this course, the students would be expected to understand classical concepts in the local theory of curves and surfaces including normal, principal, mean, curvature, and geodesies. They will also learn about tensors of different ranks.

Course Outline:

Theory of Space Curves: Introduction, index notation and summation convention. Space curves, arc length, tangent, normal and binormal Osculating, normal and rectifying planes. Curvature and torsion. The Frenet-Serret theorem. Natural equation of a curve. Involutes and evolutes, helices Fundamental existence theorem of space curves.

Theory of Surfaces: Coordinate transformation. Tangent plane and surface normal. The first fundamental form and the metric tensor The second fundamental form. Principal, Gaussian, mean, geodesic and normal curvatures. Gauss and Weingarten equations. Gauss and Codazzi equations

Tensor Analysis: Einstein summation convention. Tensors of different ranks. Contravariant, covariant and mixed tensors. Addition, subtraction, inner and outer products of tensors. Contraction theorem, quotient law. The line element and metric tensor. Christoffel symbols.

Recommended Books:

1. R. S. Millman and G. D. Parker, “*Elements of Differential Geometry”*, Prentice-Hall, New Jersey, 1977.
2. A. Goetz, “*Introduction to Differential Geometry”*. Addison- Wesley, 1970
3. E. Kreyzig, “Differential Geometry”, Dover, 1991.
4. M. M Lipschutz, “*Schaum's Outline of Differential Geometry”*, McGraw Hill, 1963.
5. D. Somasundaram, “*Differential Geometry”*, Narosa Publishing House, New Delhi. 2005.
6. M. R. Spiegel, “Vector Analysis”, McGraw Hill Book Company, Singapore, 1981.
7. A. W. Joshi, “*Matrices and Tensors in Physics”*, Wiley Eastern Limited, 1991.
8. F. Chorlton, “*Vector and Tensor Methods”*, Ellis Horwood Publisher, U.K., 1977.

MATH-673	Numerical Analysis-I	Credit Hours (3)

Prerequisites: Calculus-I, Linear Algebra

Specific Objective of Course: This course is designed to teach the students about numerical methods and their theoretical bases. The course aims at inculcating in the students the skill to apply various techniques in numerical analysis, understand and do calculations about errors that can occur in numerical methods and understand and be able to use the basics of matrix analysis.

Course Outline of the Course: Solutions of non-linear equations: the Bisection method, fixed point iteration, the method of false position, the Newton-Raphson's method, Rate of convergence of iterative methods.
Solution of linear system equations: Iterative methods (Jacobi, Guass Seidel, S. O. R).
Eigen Value Problems: The power method and inverse power method, Jacobi's method, Given's method and House Holder's method.
Interpolation: Lagrange Interpolation, Divided Differences, Nowton Forward Difference formula, Newton Backward formula, Aitken's and Inverse Interpolations, Cubic splines, Finite Difference Operators (Forward, Backward, Central and Shift).

Recommended Books:

1. *R. L. Burden and J. Douglas Faires, "Numerical Analysis", 2000, Brooks/Cole Publishing Company.*
2. *C. E. Froberg, "Introduction to Numerical Analysis", 1974, Addison Wesley Co.*
3. *M. K. Jain, "Numerical Methods for Scientific and Engineering Computation", 1993, Wiley Eastern Limited.*
4. *Dr. Faiz Ahmad and M. Afzal Rana, "Elements of Numerical Analysis", 1995, National Book Foundation.*

MATH-674	Project	Credit Hours (3)

Each student will carry a project on a mathematical problem in semester 4 and will continue the same project in the eighth semester. At the end of the eighth semester, the student will submit a copy of his thesis which will be evaluated by an external examiner.

MATH-681	Numerical Analysis-II	Credit Hours (3)

Prerequisites: Numerical Analysis-I

Specific Objective of the Course: This course is designed to teach the students about numerical methods and their theoretical bases.

Course Outline of the Course: Numerical Differentiation: Forward formulas, Central Difference formulas, Error in Numerical differentiation, Extrapolation to the limit.
Numerical Integration: The rectangular, Trapezoidal and Simpson's One-Third and Three-Eight's, Romberg Integration, Method of undetermined coefficients.
Difference and Differential equations: Formation of difference equations, Numerical Solution of Linear (Homogeneous and Non-homogeneous) difference equations with constant coefficients, Euler's methods, Taylor's methods, Runge-Kutta Method, Milne-Simpson method, Adam-Bashforth-Moulton method for solving Initial value problems along with convergence and Instability Criteria, Finite Difference method and the Shooting method for Boundary value problems.

Recommended Books:

1. *R. L. Burden and J. Douglas Faires, "Numerical Analysis", 2000, Brooks/Cole Publishing Company.*
2. *C. E. Froberg, "Introduction to Numerical Analysis", 1974, Addison Wesley Co.*
3. *M. K. Jain, "Numerical Methods for Scientific and Engineering Computation", 1993, Wiley Eastern Limited.*
4. *Dr. Faiz Ahmad and M. Afzal Rana, "Elements of Numerical Analysis", 1995, National Book Foundation*

MATH-682	**Functional Analysis**	**Credit Hours (3)**

Prerequisites: Analysis-I

Specific Objectives of course: This course extends methods of linear algebra and analysis to spaces of functions, in which the interaction between algebra and analysis allows powerful methods to be developed. The course will be mathematically sophisticated and will use ideas both from linear algebra and analysis.

Course Outline:

Metric Space: Review of metric spaces, Convergence in metric spaces, Complete metric spaces, Dense sets and separable spaces, No-where dense sets, Baire category theorem.

Normed Spaces: Normed linear spaces, Banach spaces, Equivalent norms, Linear operator, Finite dimensional normed spaces, Continuous and bounded linear operators, Dual spaces.

Inner Product Spaces: Definition and examples, Orthonorrnal sets and bases, Annihilators, projections, Linear functionals on Hilbert spaces. Reflexivity of Hilbert spaces.

Recommended Books:

1. A. V. Balakrishnan, "*Applied Functional Analysis*", 2nd edition, Springer-Verlag, Berlin, 1981.
2. J. B. Conway, "*A Course in Functional Analysis*", 2nd ed., Springer-Verlag, Berlin, 1997.
3. K. Yosida, "*Functional Analysis*", 5th ed., Springer-Verlag, Berlin, 1995.
4. E. Kreyszig, "*Introduction to Functional Analysis with Applications*", John Wiley and Sons, 2004.

MATH-683	**Project**	**Credit Hours (3)**

The project from semester seven will be continued in semester 8th. At the end of 8th semester thesis must be submitted and will be graded from an external examiner.

BS ELECTIVES

MATH- 676	**Fluid Mechanics**	**Credit Hours (3)**

Prerequisites: Knowledge of Calculus-I & II , Ordinary and Partial differential equations.

Specific Objectives of Course: Develop an understanding of fluid mechanics and its importance in mathematics and its applications in aerospace and technology. Learn to use control volume analysis to develop basic equations and to solve problems. Understand and use differential equations to determine pressure and velocity variations in internal and external flows. Understand the concept of viscosity and where viscosity is important in real flows. To model the governing equations of a flow past or inside a body of a specific geometry. Students will be able to classify fluids and will also become familiar of the laminar to turbulence transition of flows.

Course outline: Introduction: Dimensions, units and physical quantities, gases and liquids, pressure and temperature, properties of fluids, thermodynamics properties and relationship. pressure variation.
Fluid statics: pressure variation, forces on plane and curved surfaces.
Fluids in motion: Lagrangian and Eulerian description, pathlines, streaklines and steamlines, acceleration, angular velocity and vorticity, classification of fluid flows, Bernoulli's equation.
Navier Stokes equations: The integral and differential forms of the conservation of mass, momentum and energy.
Viscous flow: Incompressible viscous flow using Navier-Stokes equations, pipe flow, boundary layers, separation, introduction to turbulence.

Recommended books:

1. *D. F. Young, "A Brief Introduction to Fluid Mechanics"*, 5th Edition, Wiley, 2010.
2. H. Schlichting, "Boundary layer theory", 7th Edition, Mc Graw Hill. 1979.
3. F. M. White, "Viscous fluid flow", 3rd Edition, 2006.
4. M. Pottert & D. Wiggert, "Fluid Mechanics", Shaums Outlines series, MC Graw Hill, 2008.

MATH- 677	Algebraic Topology	Credit Hours (3)

Pre-requisite: Set Topology and Linear Algebra

Objective of the Course:
This course is designed for undergraduate students to be taught in one semester. This course is intended to the introduction of the machinery of algebraic topology. Specifically, we will focus on singular homology and the dual theory of singular co-homology.

Course Contents:
CW-complexes, delta-complexes, simplicial homology, exact sequences, diagram chasing, Singular homology, homotopies and chain homotopies, categories and functors, Eilenberg-Steenrod axioms, Excision, computations for spheres, equivalence of simplicial and singular homology, Cellular homology, Mayer-Vietoris sequences, the Mayer-Vietoris argument, homology with coefficients, Tensor products, Tor, universal coefficient theorem for homology, products of simplices, The Eilenberg-Zilber shuffle "product" map, diagonal approximations, the Alexander-Whitney map, method of acyclic models, Kunneth formula, Duality, cohomology, Ext, universal coefficients for cohomology, Projective spaces and Grassmannians, cup products, relative cup products, Dual Kunneth formula, field coefficients, cup products in cohomology of projective spaces, Manifolds, local orientations, global orientations, Cap products and choices of appropriate sign conventions, statement of Poincare duality, limits, Compactly supported cohomology, proof of Poincare duality, Finish proof of Poincare duality, Intersection pairing and cup product, Lefschetz fixed point theorem, Finish proof of Lefschetz theorem.

Recommended Books:

1. Hatcher, Allen. "*Algebraic Topology*". Cambridge, UK: Cambridge University Press, 2002.
2. Massey, William S. "*A Basic Course in Algebraic Topology*". New York, NY: Springer-Verlag, 1997.
3. Rotman, Joseph J. "*An Introduction to Algebraic Topology*". New York, NY: Springer-Verlag, 1998.
4. Munkres, James R. "*Elements of Algebraic Topology*". Boulder, CO: Westview Press, 1993.

MATH- 678	Galois Theory	Credit Hours (3)

Pre-requisites: Linear Algebra, Algebra-II, Rings and Fields.

Course Objectives: The course will discuss the problem of solutions of polynomial equations both in explicit terms and in terms of abstract algebraic structures. The course demonstrates the tools of abstract algebra (linear algebra, group theory, rings and ideals) as applied to a meaningful problem.

Course Outlines: Integral domains and Fields, Homorphisms and ideals, Quotient Rings, Polynomial rings in one indeterminate over Fields, Prime ideals and Maximal ideals, irreducible Polynomials. Algebraic and transcendental field extensions, Simple Extensions, Composite Extensions, Splitting Fields, The Degree of and Extension, Ruler and Compass Constructions. Normality and Separability.
Circle Division, The Galois Group, Toots of Unity, Solvability by Radicals, Galois Extensions, The Fundamental Theorem of Galois Theory, Galois's Great Theorem, Algebraically Closed Fields.

RECOMMENDED BOOKS:

1. Joseph Rotman, "Galois Theory", Springer-Veriog, New York, Inc. , 2005
2. Lan Steward, "Galois Theory", Chapman & Hall, New York , 2004

MATH-679	Electromagnetism	Credit Hours (3)

Prerequisites: Basic of Physics

Specific Objectives of the Course:

Course Outline: Equations of electrostatic and magnelostatic boundary conditions, Boundary value problems and methods of solution, Electrostatics and magnetostatics of macroscopic medium. Dipoles and Multipole. Dielectrics. Steady currents and their interaction. Varying Currents. Electromagnetic induction. Maxwell;s equations.Energy, momentum (polynting) vectors and stress tensor of electromagnetic fields. Wave propagation, Waves in a conducting medium, reflection and dispersion. Lorentz formula. Wave3 guide and cavity resonators. Spherical waves. Field of a uniformly moving charged particle. Field of an oscillating dipole. Diffraction of electromagnetic waves.

Recommended Books:

1. *V.C.A. Ferraro, "Electromagnetic Theory", ELBS London, 1950*
2. *Lorrain & Corson,Electromagnetic Fields and Waves, Toppan Company Ltd. 1970*
3. *C.A.Coulson, Electricity, Liver & Boyd Edinburgh. 1951*
4. *A.S. Ramsey, Electricity & Magnetism, Cambridge University Press. 1952*
5. *J.R. Reitz, F.J. Milford & Christy, "Foundation of Electromagnetic Theory". London, 2008*

MATH-6710	Modeling and Simulations	Credit Hours (3)

Prerequisite(s): Partial-Differential Equations

Specific Objectives of course:
Mathematics is used in many areas such as engineering, ecological systems, biological systems, financial systems, economics, etc. In all such applications one approximates the actual situation by an idealized model. This is an introductory course of modeling, consisting of three parts: modeling with ordinary differential equations and their systems; partial differential equations; and integral equations.

The course will not be concerned with the techniques for solving the equations but with setting up the equations in specific applications. Whereas the first two types of equations have already been dealt with, the third type has not. Consequently, solutions of the former will be discussed but of the latter will rarely be touched upon.

Course Outlines:
Concepts of model, modeling and simulation Functions, linear equations, linear-differential equations, nonlinear-differential equations and integral equations as models, introduction to simulation techniques
Ordinary-Differential Equations: Modeling with first order differential equations: Newton's law of cooling; radioactive decay; Motion in a gravitational field; Population growth; Mixing problem; Newtonian mechanics. Modeling with second order differential equations: Vibrations; Application to biological systems; Modeling with periodic or impulse forcing functions; Modeling with systems of first order differential equations; Competitive hunter model; Predator prey model.

Recommended Books:

1. Giordano FR, Weir MD, "*Differential Equations: A Modeling Approach*", Addison- Wesley, Reading, Ma, USA (suggested text), 19994.
2. Jerri AJ, "*Introduction to Integral Equations with Applications*", Marcel Dekker, New York, 1985.
3. Myint UT, Debnath L, "*Partial Differential Equations for Scientists and Engineers*", 3rd edition, North Holland, Amsterdam, 1987.

MATH- 6711	**Measure Theory**	**Credit Hours (3)**

Prerequisites: Real Analysis

Specific Objectives of the Course:

Course Outline: Lebesgue measure, Outer measure. Measurable set and Lebesgue measure, A non-measurable set, measurable function. The Lebesgue Integral: The Lebesgue integral of a bounded function. The general Lebesgue integral. Lebesgue integral and its relation to Riemann integral. Convergence in measure.Measure space, Measurable functions. Integration, General convergence theorems. Signed measures. The Radon-Nikodym theorem. The L_p -spaces, Outer measure and measurability, the extension theorem, The Lebesgue Stieltjes integral, product measure. Inner Measure.

Recommended Books:

1. *H.L.Royden; "Real analysis", The McMillian Company, 1968.*
2. *D de Barra; "Measure Theory & Integration", Eillis Horwood Ltd, 1981.*
3. *P.R. Halmos., "Measure theory", Von Nostrand NY, 1950.*
4. *A Mukherjca; "Real and Functional Analysis", Plenum and K.Pothoven Press, 1978.*
5. *Seymour Lipschutz, "Set Theory and Related Topics", McGraw-Hill Publishing C,1998 .*

MATH- 6712	Rings and Modules	Credit Hours (3)

Pre-requisites: Group Theory and linear algebra

Specific objective of course: To know about basic structure of ring and modules.

Course Outline: definition of ring, with examples, ring of continuous functions, Boolean ring, ring with unity, sub-ring with examples, direct-product of rings, characteristics of ring, integral domain., definition of ideal with examples, basic property of ideals, algebra of ideals, quotient ring, homomorphism of rings definition and basic properties, fundamental theorem of ideals, definition of modules with examples sub-modules, direct sum of modules quotient modules and Homomorphism of modules.

Recommended Book:

1. C. Musili, "Introduction to Rings and Modules", Norosa Publishing house , 1994
2. *B. Farb, R. Dennis, "Noncomutative Algebra (Graduate texts in Mathematics)" Springer , 1993.*

MATH- 6713	Projective Geometry	Credit Hours (3)

Pre-requisite: Differential Geometry

Specific Objective of Course:

This course is designed to introduce the students with basic notions and intuitions on projective geometry. Projective geometry has interesting visual computing domains, especially in computer graphics. It provides a mathematical formalism that enables us to manipulate 2D projections of 3D objects. Projective geometry has a fundamental aspect that objects at infinity can be represented and manipulated which is not possible in the Euclidean geometry.

Course Outline:
Projective Spaces-Definition, Properties, the hyper plane at infinity, The projective line-Projective transformation of P1, The cross-ratio, The Projective Plane-points and lines, line at infinity, homographies, conics, Affine, Euclidean transformations, Particular transformation, Transformation hierarchy.

Recommended Books:
1. J.G. Semple and G.T. Kneebone, "*Algebraic projective geometry*", Clarendon Press, Oxford , 1952
2. R. Hartley and A. Zisserman, "*Multiple View Geometry*", Cambridge University Press , 2000.
3. O. Faugeras and Q-T. Luong, "*The Geometry of Multiple Images*", MIT Press, 2001.
4. D. Forsyth and J. Ponce, "*Computer Vision: A Modern Approach*", Prentice Hall, 2003.

MATH- 6714	Riemannian Geometry	Credit Hours (3)

Prerequisites: Algebra-I, Calculus-I, Set Topology

Specific Objectives of the Course: Riemannian Geometry provide an important tool in modern mathematics, impacting on diverse areas from the pure to the applied. The main aim of this course is to give a thorough introduction to the theory of abstract manifolds, which are the fundamental objects in Riemannian Geometry, in particular the notion of geodesics and curvature. We will be able to analyze manifolds with constant curvature, with a focus on the sphere and hyperbolic space.

Course Outlines: Definition and examples of manifolds; Submanifolds; smooth maps; Tangents; Coordinate vector fields; Tangent spaces; Dual spaces; Algebra of tensors; Vector fields; Tensor fields; Integral curves; Affine connections and Christoffel symbols; Covariant differentiation of tensor fields; Geodesics equations; Curve on manifold; Parallel transport; Lie transport; Lie derivatives and Lie Brackets; Geodesic deviation; Differential forms; Introduction to integration theory on manifolds; Riemannian Curvature tensor;. Geodesics, exponential map, curvature and examples. Completeness and Hopf-Rinow Theorem; Manifolds with constant curvature, sphere, geometry of hyperbolic space.

Recommended Books:

1. Bishop, R.L. and Goldberg, S.I., "Tensor Analysis on Manifolds". 1st ed. NY: Dover Publications, 1980
2. Carmo M.P, "Riemannian Geometry". 1st ed. Boston:Birkhauser, 1992.
3. Lovelock, D. and Rund, H. Tensors., "Differential Forms and Variational Principles", John-Willey, 1975.
4. Langwitz, D.," Differential and Riemannian Geometry", Academic Press, 1970.
5. Abraham, R., Marsden, J.E. and Ratiu, T., Manifolds, "Tensor Analysis and Applications", Addison-Wesley, 1983.

MATH- 6715	General Relativity	Credit Hours (3)

Pre-requisite: Special Relativity

Objective of the Course:
After the birth of Einstein's special theory of relativity, Minkowski reformulated it geometrically. This reformulation brought a revolution in the history of physics. To check the consistency of new theories, experiments were designed which in turn developed our scientific technology. This course is designed to introduce the students with theories presented in general relativity and explain the predictions it made. Both physical and mathematical aspects of general relativity are discussed in a systematic way.

Course Contents:
Vectors, One forms and the Metric, Manifolds, Parameterized curves, Tangent vectors, Vectors in curved space, The metric tensor and covariant differentiation, The curvature, Ricci and Weyl tensors, Curves in manifolds; parallel transport, Geodesics, Bianchi identity, Lie derivative and Isometries. Energy momentum tensor, Killing vectors, Brief literature review of symmetries in general relativity.

Recommended Books:

1. Robert M. Wald, "*General Relativity*", The University of Chicago Press, 1984.
2. David McMahon, "*Rrelativity Demystified*", Tata McGraw-Hill, New Delhi 2006.
3. G. S. Hall, "*Symmetries and curvature structure in general relativity*", World Scientific, 2004.

MATH- 6716	Mathematical Modeling	Credit Hours (3)

Prerequisites: Partial Differential equations, vector analysis, Programming in MATLAB

Specific Objectives of the Course: At the end of the course, students will be able to model problems from everyday life and diverse applications in science.

Course Outline:
Concept of model, modeling and simulation, Functions, linear equations, linear-differential equations, nonlinear-differential equations and integral equations as models, introduction to simulation techniques
Ordinary-Differential Equations: Modeling with first order differential equations: Newton's law of cooling; radioactive decay; motion in a gravitational field; population growth; mixing problem; Newtonian mechanics. Modeling with second order differential equations: vibrations; application to biological systems; modeling with period or impulse forcing functions. Modeling with systems of first order differential equations; competitive hunter model; predator prey model
Partial-Differential Equations: Methodology of mathematical modeling; objective, background, approximation and idealization, model validation, compounding. Modeling wave phenomena (wave equation); shallow water waves, uniform transmission line, traffic flow, RC circuits. Modeling the heat equation and some application to heat conduction problems in rods, lamina, cylinders etc. modeling the potential equation (Laplace equation), application in fluid mechanics, gravitational problems. Equation of continuity.

Recommended Books:

1. *Giordano FR, Weir MD, "Differential Equations": A Modeling Approach, Addison-Wesley, Reading, Ma USA, 1994*
2. *Jerri AJ, "Introduction to Integral Equations with Applications", Marcel Dekker, New York, 1985*
3. *Myint UT, Debnath L, "Partial Differential Equations for Scientists and Engineers (3rd edition)", North Holland, Amsterdam, 1987*

MATH-6717	Axiomatic Set Theory	Credit Hours (3)

Prerequisites: Some knowledge of first order logic will be an advantage, knowledge of basic set theory.

Specific Objective of the Course: After studying this course the students will be able to:

Be familiar with the axiomatic basis of the theory of the universe of sets of mathematical discourse. Be able to understand the notion of an "inner model" of set theory. Be able to understand how such models enable consistency statements. Have a working knowledge of the constructability hierarchy. Be able to understand Zermelo-Fraenkel axiom system ZFCfor set theory with the axiom of choice and with how ZFC may serve as a formalization of mathematics. Be able to understand the equivalence of the well ordering principle. Have a knowledge of the axiom of choice and Zorn's lemma.

Course Outlines:.
Basics: Classes and Sets, Special Classes.
Boolean algebra of Classes: Boolean Class Operators, Boolean Algebra, Order, Singletons and Class Pairs, Infinite Boolean Operators, Power Class Building.
Sets, Relations and Functions: Sets, Ordered Pair, Cartesian Product, Relations, Relation Algebra, Equivalence Relations, Maps and Functions,
Natural Numbers: Foundation and Infinity, Definition and Basic Properties, Induction, Sequences and Normal Functions.
Recursion: Axiom of Choice, Well-Ordering, Applications of the Axiom of Choice.
The Axioms of ZFC: Tentative Axioms, The Axioms of Zermelo-Fraenkel Set Theory with Choice, Class terms, relativisations to models, Absoluteness and reflection theorems, Introduction to Consistency proofs, Closed and unbounded sets, stationary sets, Regular and singular cardinals,

cofinality; inaccessible cardinals, Goedel's Def function and the definition of the constructible hierarchy L, The Consistency of AC and GCH with ZFC.

Recommended Books:

1. P. Suppes, "*Axiomatic Set Theory"*, Dover Publication, United States", 1960.
2. Dana S. Scott, Thomas J. Jech, "*Axiomatic Set Theory"*, American Mathematical Society, Providence, Rhodes Island, 1967.
3. P. Burnays. "*Axiomatic Set Theory"*, Dover Publication, United States, 2003.
4. J. L. Krivine, "*Introduction to Axiomatic Set Theory"*, Springer, Netherlands, 1973.

MAth-685	Dynamical Systems	Credit Hours (3)

Prerequisite: Linear Algebra and Calculus

Specific Objectives of Course:

One Dimensional Dynamics: Elementary definitions of dynamical systems**,** hyperbolicity**,** the quadratic family**,** symbolic dynamics, structure stability**,** chaos**,** bifurcation theory
Higher Dimensional Dynamics: The dynamics of linear maps, attractors**,** the stable and unstable manifold theorems**,** global results and Hyperbolic sets, Periodic points.

Recommended books

1) Robert L. Devaney, "*Chaotic Dynamical Systems* (second edittion)", Westview Press, 1992.
2) A. N. Michel, Ling Hou, Derong Liu, "*Stability of Dynamical Systems"*, Birkhauser, 2008.
3) Morries, W. Hirich, Stephen smale, Robert L. Devaney, *"Differential Equations, Dynamical systems and Introductio to Chaos",* (Third edition), Elsevier inc, 2012.

MATH- 686	Computational Fluid Dynamics	Credit Hours 3 (2+1)

Prerequisites: Knowledge of Calculus-I & II , Ordinary and Partial differential equations, Fluid Mechanics, Numerical Analysis, Mat Lab or Fortran or C.

Specific objectives of course:
At the end of this course students will be able to apply numerical techniques of finite difference method to solve partial differential equations related to fluid dynamics. Finite difference techniques will be studied in detail with examples. Students will also be able to built computer programmes for numerical solutions of partial differential equations related to flow phenomena. Students will be able to sketch and analyze various solutions based on the output of the computer programmes. Laminar flow equations for flow due to a rotating disk will be modelled and solved numerically with programmes in Mat Lab or any other language.

Course outline: A brief review of Navier Stokes equations. Numerical Methods for modeling parabolic and elliptic equations: Model equations, discretization of derivatives with finite differences, finite difference method for parabolic equations, explicit method with various boundary conditions, implicit methods, Crank Nicolson and Keller Box schemes with examples and programming.
Finite difference methods for hyperbolic partial differential equations with examples and computer programmes.

The laminar boundary layer flow over rotating disk with programming and visualizations.

Recommended books:

1. T. Cebbeci, J. Shao, F. Kafayeke, E. Laurendeau, "Computational Fluid Dynamics for engineers", Horizons publishing, 2005.
2. H. Schlichting, "Boundary layer theory", 7th Edition, Mc Graw Hill. 1979
3. F. M. White," Viscous fluid flow", 3rd Edition, 2006.
4. S. Iengar, D. Jain, "Numerical Methods", New age international (P) Ltd. 2009.

MATH- 687	History of Mathematics	Credit Hours (3)

Course prerequisite: The prerequisite for this course is an intense interest in mathematics. There are no other prerequisites for it other than a familiarity with plane geometry and algebra.

Specific Objective of Course objectives:
After studying this course the students will be able to describe the development of various areas of mathematics within and across various civilizations describe the changing character of mathematics over time and recognize the distinction between formal and intuitive mathematics give examples of significant applications of mathematics to commerce, science, and general life, past and present understand that history includes the interpretion the past, not just facts better research historical questions and present your conclusions to others

Course Outline

Early Number Systems and Symbols: Primitive Counting, Number Recording of the Egyptians and Greeks, Number Recording of the Babylonians.

Mathematics in Early Civilizations: The Rhind Papyrus, Egyptian Arithmetic, Four Problems from the Rhind Papyrus, Egyptian Geometry, Babylonian Mathematics, Plimpton 322.

The Beginnings of Greek Mathematics: The Geometrical Discoveries of Thales, Pythagorean Mathematics, The Pythagorean Problem, Three Construction Problems of Antiquity, The Quadratrix of Hippias.

The Alexandrian School, Euclid: Euclid and the Elements, Euclidean Geometry, Euclid's Number Theory, Eratosthenes, the Wise Man of Alexandria, Archimedes.

The Twilight of Greek Mathematics, Diophantus: The Decline of Alexandrian Mathematics, The Arithmetica, Diophantine Equations in Greece, India, and China, The Later Commentators, Mathematics in the Near and Far East.

The First Awakening: Fibonacci: The Decline and Revival of Learning, The *Liber Abaci* and *Liber Quadratorum*, The Fibonacci sequence, Fibonacci and the Pythagorean Problem.

The Renaissance of Mathematics: Cardan and Tartaglia**:** Europe in the Fourteenth and Fifteenth Centuries, The Battle of the Scholars, Cardan's *Ars* Magna, Ferrari's Solution of the Quartic Equation.

The Mechanical World: Descartes and Newton: The Dawn of Modern Mathematics, Descartes: The Discours de la Methode, Newton: The *Principia Mathematica*, Gottfried Leibniz: The Calculus Controversy.

The Development of Probability Theory: Pascal, Bernoulli, and Laplace**:** The Origins of Probability Theory, Pascal's Arithmetic Triangle, The Bernoullis and Laplace.

The Revival of Number Theory: Fermat, Euler, and Gauss**:** Marin Mersenne and the Search for Perfect Numbers, From Fermat to Euler, The Prince of Mathematicians: Carl Friedrich.

Nineteenth−Century Contributions: Lobachevsky to Hilbert: Attempts to Prove the Parallel Postulate, The Founders of Non-Euclidean Geometry, The Age of Rigor, Arithmetic Generalized.

Transition to the Twentieth Century: Cantor and Kronecker**:** The Emergence of American Mathematics, Counting the Infinite, The Paradoxes of Set Theory.

Extensions and Generalizations: Hardy, Hausdorff, and Noether: Hardy and Ramanujan, The Beginnings of Point-Set Topology, Some Twentieth-Century Developments.

Recommended Books:

1. *D. M. Burton, "The History of Mathematics", An Introduction, 6th Edition, McGraw-Hill Primis, 2010.*
2. *J. R. Durbin, "Mathematics: Its Spirit and Evolution". Boston: Allyn and Bacon, 1973.*
3. *R. Cook, "The History of Mathematics: A Brief Course. 2nd edition", New York: Wiley.*
4. *R. Courant and H. Robbins, "What is Mathematics? An Elementary Approach to Ideas and Methods", 2nd edition, Revised by Ian Stewart. Oxford: Oxford University Press, 1996.*

MATH-688	Pointless Topology	Credit Hours (3)

Prerequisites: Knowledge of Topology.

Specific Objectives of Course:

Topological spaces have points and open sets, but many definitions and theorems can be stated purely in terms of the behavior of open sets, without reference to points. This leads to a formulation of topological ideas in more abstract spaces, called locales that may not have any points.

Course Outline:

Introduction: Spaces and Lattices of open Sets, Sober spaces, the axiom TD: another case of spaces easy to reconstruct, Aside: several technical properties of TD-spaces.

Frames and Locales Spectra: Frames, Locales and locales maps, Points, Spectra, The unit σ and spatiality, The unit λ and sobriety.

Sublocales: Extremal monomorphisms in Loc, Sub locales, The co-frame of sub locales, Images and preimages, Alternative representations of sub locales, Open and closed sub locales, Open and closed localic maps, Closure, Preimage as a homomorphism, Other special sub locales, one-point sub locales and Boolean ones , Sub locales as a quotients.

Separation Axioms: Instead of T_1: subfit and fit, Mimicking the Hausdorff axiom , I-Hausdorff frames and regular monomorphisms, Aside: Raney identity , Quite like the classical case: Regular, completely regular and normal.

Compactness and Local Compactness: Compactness and separation, Compactification, Continuous completely regular frames, Hofmann-Lawson duality.

Metric Frames: Diameters and metric diameters, Metric spectrum, Uniform Metrization Theorem, Metrization theorems for plain frames, Categories of metric frames.

Connectedness: A few observations about sub locales, Connected and disconnected locales, Locally connected locales.

Recommended Books:

(1) *B. Banaschewski, "The Real numbers in Pointfree topology", Textos de Matematica vol. 12, Coimbra, 1997.*
(2) *Jorge Picado and Ales Pultr , "Topology without points", Springer Basel.*
(3) *B. Banaschewski, "Uniform completion in Pointfree topology", vol. 20, Kluwer Academic Publishers, Boston, Dordrecht, London, 2003.*

MATH- 689	Quantum Mechanics	Credit Hours (3)

Prerequisites: Mechanics

Specific Objectives of the Course:

Course Outline: Inadequacy of Classical Mechanics. Black body rediation. Photoelectric Effect, Comption Effect, Bohr's theory of atomic structure, Wave-Particle duality, De-Broglies postulate. The Uncertainty Principle.Uncertainty of position and momentum, statement and proof of the uncertainty principle, Energy-time uncertainty. Eigenvalues and Eigenfunctions, Operators and

Eigenfunctions, Linear Operators, Operators formulism in Quantium Mechanics, Orthonormal system, Hermitian operators and their properties, Simultaneous Eigen-functions, Parity operators. Postulate of quantium mechanics, Schroedinger Wave. Equation. Motion in One Dimension. Step Potential, Potential Barrier, Potential Well, harmonic Oscillator. Motion in Three Dimensions, Angular Momentum, Pauli Exclusion Principle, Hydrogen atom. Heisenberg equationsw of motion and equivalence of Schrodinger and Heisenberg physical pictures. Scattering theory. Born approximation. Partial wave analysis. Optical theorem. Time dependent & time independent perturbation theory. Selection rules. Klein-Gordon equation. Dirac's equation. Spin angular momentum.

Recommended Books:

1. *R.L. White, Basic Quantum Mechanics, McGraw Hill Book Co. N.Y, 1966.*
2. *L.I. Schiff, Quantum Mechanics, McGraw Hill Kogakusha Ltd.,1955*
3. *P.T. Mathews, Introduction to Quantum Mechanics, McGraw Hill Book Co. 1956*
4. *Dicke & Wittike, Introduction to Quantum Mechanics, Addison Wesley Publishing Company Inc.,1966.*
5. *F.Mandl, Quantum Mechanics, Butterworth, 1966, London. 7th Impression.*
6. *P.M. Mathews, K.V.Venkatesan, A Text Book of quantum Mechanics 8th Reprint, Tata McGraw Hill Publishing Company Limited, New Delhi, 1984*
7. *P.A.M.Dirac, Introduction to Quantum Mechanics.*
8. *Riazuddin and Fayyazuddin, Introduction to Quantum Mechanics, World Scientific, 1990.*

MATH-6810	Lie Groups and Lie algebras	Credit Hours (3)

Pre-requisite: Fundamental concepts of group theory and Differential geometry

Specific Objectives of the Course: Representation theory is a powerful tool because it reduces problems in abstract algebra to problems in linear algebra, a subject that is well understood. Furthermore, the vector space on which a group (for example) is represented can be infinite-dimensional and by allowing it to be, for instance, a Hilbert space, methods of analysis can be applied to the theory of groups. Representation theory is also important in physics because, for example, it describes how the symmetry group of a physical system affects the solutions of equations describing that system. This course covers the structure of Lie groups, Lie algebras and their (complex) representations.

Course outlines:
Definition of Lie group and Lie algebra, The exponential mapping, Matrix Lie groups, Complex Lie groups, Infinite dimensional Lie groups, Cartan's theorem on closed subgroups, The adjoint representation, Universal covering groups, The universal enveloping algebra, Compact Lie groups, Representation of Lie groups on finite dimensional vector space and on Hilbert space, Lie Subgroups, Properties of Lie algebra, Lie subalgebra, Actions of Lie groups and Lie algebras,Structure constants, Direct sums, Lie algebra of matrix Lie groups, Universal Enveloping Algebras,

Recommended books:

1. Gilmore, R. : Lie Groups, Lie Algebras and Some of Their Applications ,Dover Publication, 2006.
2. Erdmann, K. and Mark, W. Introduction to Lie Algebras , Springer, 2006.
3. Iachello, F. Lie Algebras and Applications , Springer, 2006.
4. Hall, B. Lie groups, Lie algebras and representations ,Springer, 2003.

MATH-6811	Introduction to Econometrics	Credit Hours (3)

Prerequisites: Statistics, Calculus, MATLAB

Specific Objectives of course: This course focuses on techniques for estimating regression models, on problems commonly encountered in estimating such models, and on interpreting the estimates from such models. The goal of the course is to teach the basics of the theory and practice of econometrics and to give an experience in estimating econometric models with actual data. This course will help the students, taking their research areas in applications of mathematics in economics and social sciences.

Course Outline: Simple linear regression; Multiple linear regression-estimation; Multiple linear regression-inference; Multiple regression-OLS asymptotic; Multiple regression-further issues; Multiple regression-qualitative variables; Heteroskedasticity; Data problems; Simple panel data methods; Causality.

Recommended Books:

1. Jeffrey Wooldridge, *Introductory Econometrics*, 4th edition [WR], 2009.
2. Acock, Alan, "*A Gentle Introduction to Stata*", 3rd edition, College Station: Stata Press, 2010.

MATH- 6812	Module Theory	Credit Hours (3)

Prerequisite: MATH-241 Algebra-I

Course Objectives: In abstract algebra, the concept of a module over a ring is a generalization of the notion of vector space over a field, where the corresponding scalars are the elements of an arbitrary ring. Modules also generalize the notion of abelian groups, which are modules over the ring of integers. Much of the modern development of commutative algebra emphasizes modules. Both ideals of a ring R and R-algebras are special cases of R-modules, so module theory encompasses both ideal theory and the theory of ring extensions. This course focuses the basic concepts and results of Module Theory.

Course outlines:
Modules, submodules, operations on submodules, generation of modules, finitely generated modules, direct sum of modules, cyclic modules, free modules, quotient modules, homomorphisms of modules, isomorphism theorems of modules, short exact sequences of modules, group of module homomorphisms, simple modules, modules over PID's, Artinian Modules, Noetherian Modules, modules of finite length, Artinian rings, Noetherian rings.

Recommended Books:

1. Adamson, J.,1976. Rings and modules 1st ed. NY: Chelsea.
2. Blyth, T.S., 1977. Module Theory. 1st ed. Oxford University Press.
3. Hartley, B. and Hawkes, T.O. Rings, Modules and Linear algebra. 1st ed. Chapman and Hall, 1980.
4. David S Dummit, Richard M. Foote, Abstract Algebra, (third edition), John Wiley & Sons.Thomas W, 2004.
5. Hungerford, Algebra, Springer-Verlag, New York Inc. 1974

MATH- 6813	Graph Theory	Credit Hours (3)

Pre-requisites: Set Theory, Mathematical Logic, Discrete Mathematics.

Course Objectives: The objective of this course is to introduce students to some of the most important notions of graph theory and develop their skill in solving basic exercises. Students should also become able to identify graph theory problems in a natural way even when they appear in a different setting.

Course Outlines: Basic definitions, isomorphisms, walks, cycles and bipartite graphs, Components, cut-edges, Eulerian graphs, vertex degrees and degree sequences, directed graphs, Eulerian digraphs, trees and distance, Counting spanning trees and the matrix tree theorem, minimal spanning trees and shortest paths, Matchings, Hall's theorem and coverings, maximum matchings, factors, Cuts and connectivity, Network flow problems, max-flow min-cut theorem, Vertex colorings, bounds on chromatic numbers and Mycielski's construction, Chromatic polynomials, chordal graphs, planar graphs, Euler's formula and Kuratowski's theorem, five and four color theorems.

Recommended Books:

1. Introduction to Graph Theory by Douglas B. West, Second edition, 2000.
2. G. Chartland, P. Zhang, "A first course in graph theory", Dover Books, 2012.

MATH-6814	Special Relativity	Credit Hours (3)

Pre-requisite: Electricity and Magnetism

Specific Objective of the Course:

Newton, Faraday and Maxwell made remarkable contributions in the development of Physics. There was still disagreement on ether theory and interpretation was needed to explain some physical laws. Meanwhile, in 1905 Einstein published two papers, one on quantum of radiation and other on electrodynamics of moving bodies. His later paper on electrodynamics of moving bodies proved to be a base for special theory of relativity. In this theory Einstein gave explanation to different phenomenon by using simple kinematics for frames of constant velocity. In this course we will learn special theory in a way that will lead us easily to the generalization of the theory.

Course Contents:
Development of the Pre-Newtonian and Newtonian theories of motion. Einstein's special theory of relativity: length contraction, time dilation and simultaneity; velocity addition for 1-d motion. The extension of special relativity to 3-dimensions. Invariant quantities and tensors. Coordinate transformations. The 4-vector formulation of special relativity; its geometric and group aspects. Physical applications of special relativity: Doppler effect; Compton effect; particle scattering; particle production, decay and binding energy. Use of 4-vector formulation for electromagnetism and its consequences gauge transformations and gauge groups. Special relativity with small accelerations and its geometrical implications.

Recommended Books:

1. Asghar Qadir, *"Relativity: An Introduction to the Special Theory"*, World Scientific, 1989.
2. M. Born, *"Einstein's Theory of Relativity"* , (Revised Edition), Dover Publications, 1962.
3. Vidwan Singh Soni, *"Mechanics and Relativity"*, Asoke K, Ghosh Publishing New Delhi 2009.

MATH-6815	Optimization Theory	Credit Hours (3)

Prerequisites: Calculus-I, Numerical Analysis-I
Specific Objectives of the Course: At the end of the course, students will be able to solve practical problems of optimization.

Course Outline
Statement of the problem, condition for optimality, concept of direction of search, alternating direction and steepest descent methods, conjugate direction method, conjugate gradient method, Newton's method, Quasi-Newton equation, derivation of updating formulae for Quasi-Newton's equation, The Gauss-Newton method, The levenberg-Marquart method, The corrected Gauss-Newton method, Methods for large scale problems. Theory of constrained optimization, methods for minimizing a general function subject to linear equality constraints, active set strategies for linear inequality constraints, special forms of the objectives functions, Lagrange multiplier estimates, Changes in working set, Barries function methods, Penalty functions methods, Methods based on Langrangian functions reduced gradient and gradient projection methods.

Recommended Books:
1. *Gill, P.E., Murray E & Wright, H.H. "Practical Optimization", Academic Press, 1981.*
2. *Fletcher, R. "Practical Methods of Optimization", Vol.I & II, john Wiley and Sons, 1980.*
3. *David G.Luenberger, " Optimization by Vector Space Methods", John Wiley & Sons, 1986*
4. *Gotfreid BS, Weisan J, "Introduction to Optimization Theory", Prentice Hall, Englewood Cliffs, NJ, USA, 1973.*
5. *S.S. Rao., "Optimization Theory and Application", Wiley Eastern Ltd, 1984.*
6. *Bazaraa, M.S. and Shetty, C.M., "Nonlinear Programming", Theory and Algorithms, John Wiley & Sons, 1979.*

MATH-6816	Category Theory	Credit Hours (3)

Pre-requisites: Basic knowledge of Group theory, Ring Theory, Modulus Theory, Linear algebra and Functional analysis.

Specific object of the course: To know about basic structure of categories Theory.

Course Outline: Basic Concepts of categories: Categories of Metric spaces, Co-Equalizers and Equalizers , Constructions in categories of metric spaces, Definition of category, Epimorphism and Monomorphism , Limit and Co-Limit. Product and Co- product, Vector space and Posets.

Recommended Books:

1. *Michael A. Arbib and Ernest G. Manes, "Arrows, structures and functions", academic press, 1975,*
2. *T.S. Blyth, "Categories", Longman Sc & Tech,* 1986.

MATH-6817	**Convex Analysis**	Credit Hours (3)

Prerequisite: Calculus-I

Course Objectives: Convex analysis deals with the study of convex sets and convex functions. There is main connection between convex functions and convex sets, namely the domain of convex functions must be a convex set. Convex functions play an important role in many fields of mathematics such as optimization, control theory, operations research, geometry, differential equations, functional analysis etc. as well as in applied sciences e.g. in economics and finance. They have a lot of interesting and fruitful properties, e.g. continuity and differentiability properties or the fact that a local minimum turns out to be a global minimum etc. They even allow to establish a proper and general theory of convex functions. In this course we will learn some basic theory of convex functions and convex sets and some related results.

Course Outlines:
Convex set, J- Convex function, convex and log- convex function, continuity and differentiability of convex function, epigraph of convex function, relation between convex and J- convex functions, Characterizations, Differences of convex functions, Affine function, sub differential of convex function, support line of convex functions, Conjugate convex functions, affine sets, convex and affine hull.

Recommended Books:

(1) *A. W. Roberts and D. E., "Varberg, Convex functions", Academic Press, New York, 1973.*
(2) *C. P. Niculescu and L. E. Persson, "Convex functions and their applications", CMS Books in Mathematics, Springer-Verlage, New York, 2006.*
(3) *R. T. Rockafellar, Convex Analysis, "New Jersey Princeton University", 1972.*
(4) *B. Simon, "Convexity An analytic view point", Cambridge University, 2011.*